

Nature, origin, potential composition, and climate impact of the Asian Tropopause Aerosol Layer (ATAL)

T. D. Fairlie¹, J.-P. Vernier^{1,2}, L.W. Thomason¹, M. Natarajan¹

1. NASA Langley Research Center, Hampton, Virginia, USA

2. Science Systems and Applications, Inc., Hampton, Virginia, USA

contributions from K. Bedka¹, F. Wienhold⁴, J. Bian⁵ and B. Martinsson⁶,

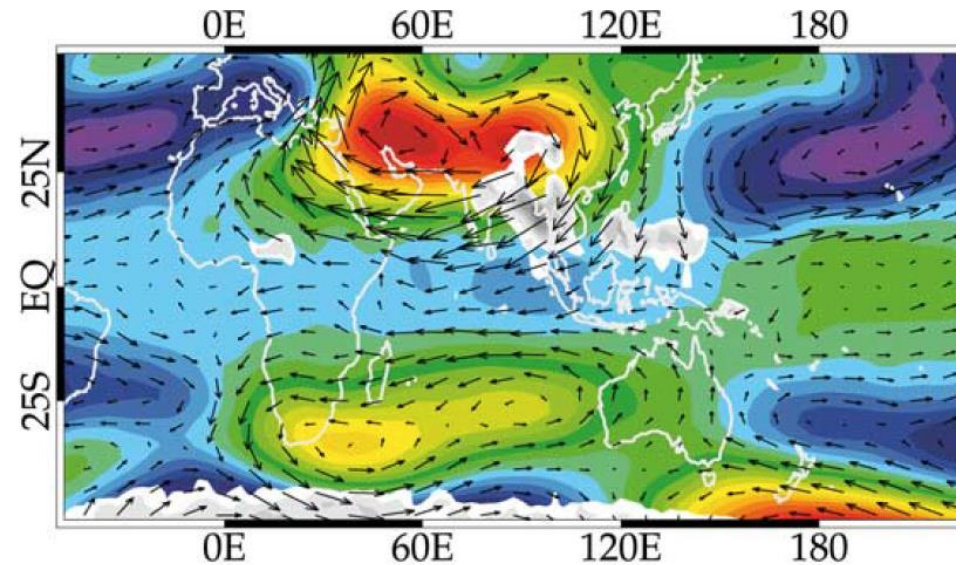
4. Swiss Federal Institute of Technology, Zurich, Switzerland.

5. LAGEO, Institute of Atmospheric Physics, Chinese Acad. Sci., Beijing, China.

6. Lund University, Sweden.

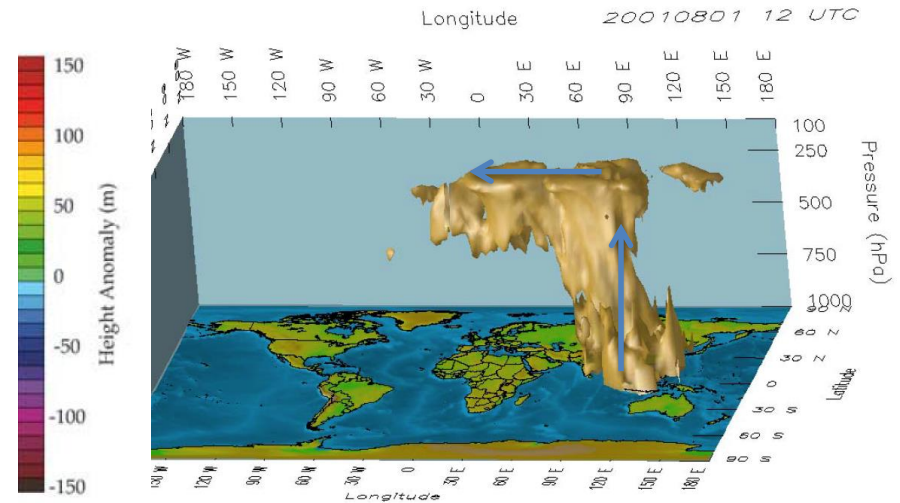
Transport of pollution in the Upper Troposphere by Asian Monsoon

MLS/CO July-Aug 05 100hPa



Park et al. (2006)

ECHAM Model CO



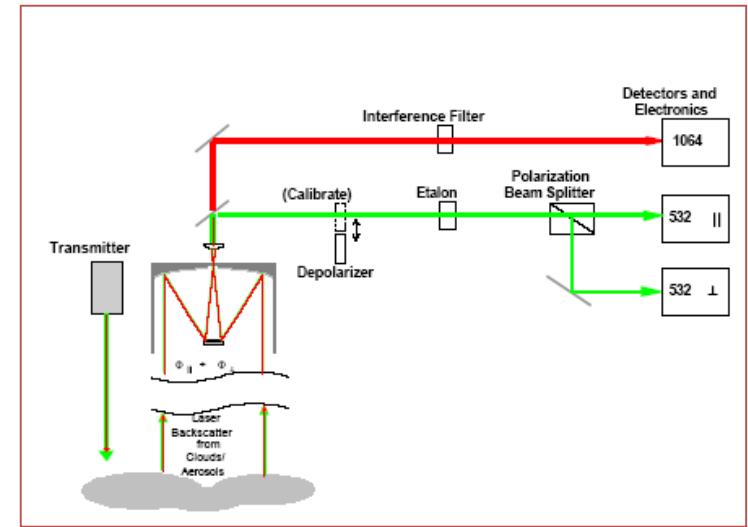
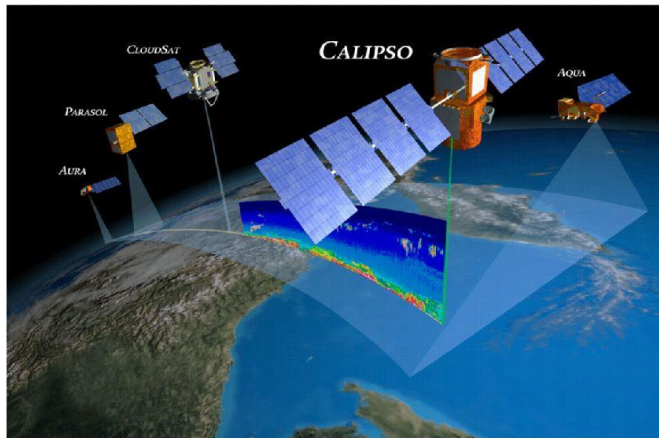
(Lawrence et al., 2010, ACPD)

- Enhanced levels of CO observed in the Upper Troposphere (UT) within the Asian Anticyclone
- CO is lifted up from Southeast Asia to the UT by convection in monsoon
- Other tracers of pollution (e.g. HCN) also peak here during the monsoon (Randel et al. 2010)
-

Questions: (1) Do we see a similar maximum in the UT for aerosols during the Asia Monsoon? (2) Is deep convection in the monsoon an effective means to transport aerosols to the stratosphere?

The CALIOP lidar characteristics

- A-train
- Eq crossing time
: 1h30 am/pm
- 16 days repeat cycle



Scattering Ratio

$$SR = \frac{b_{(^{+//})532}}{b_m}$$

~ Particle mixing ratio

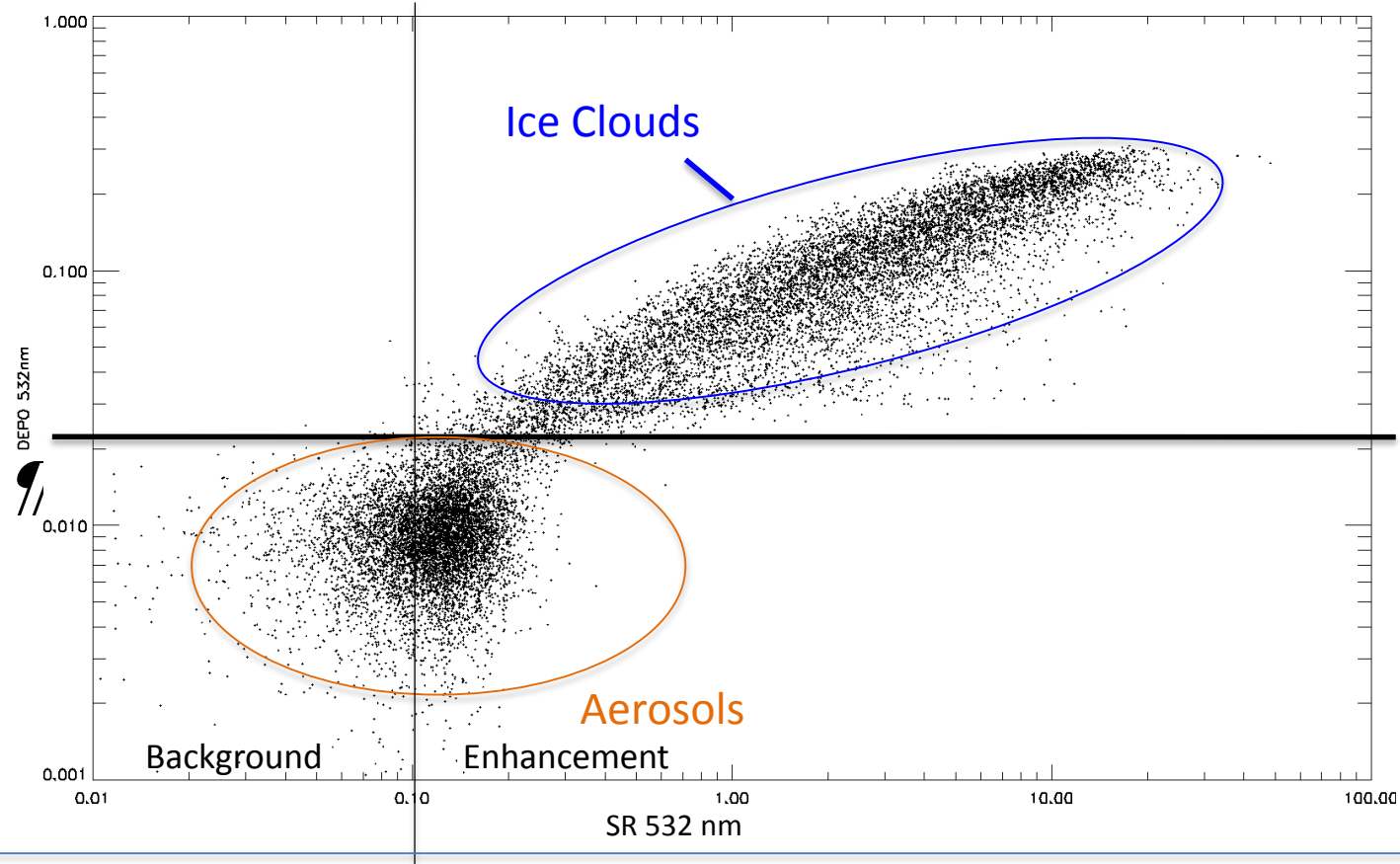
$$\rho = \frac{b_{(^{+//})532}}{b_{(^{\perp})532}}$$

Depolarization Ratio

~ particle shape

- CALIPSO nadir view : 80-180m resolution in the UTLS
- depolarization and color ratio provide information on aerosol shape and size

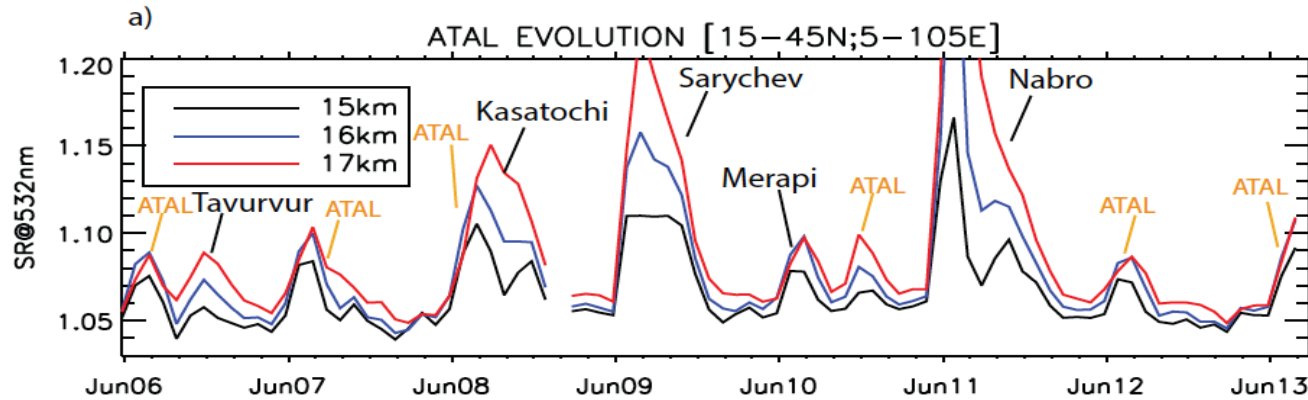
Cloud clearing (Vernier et al., 2009)



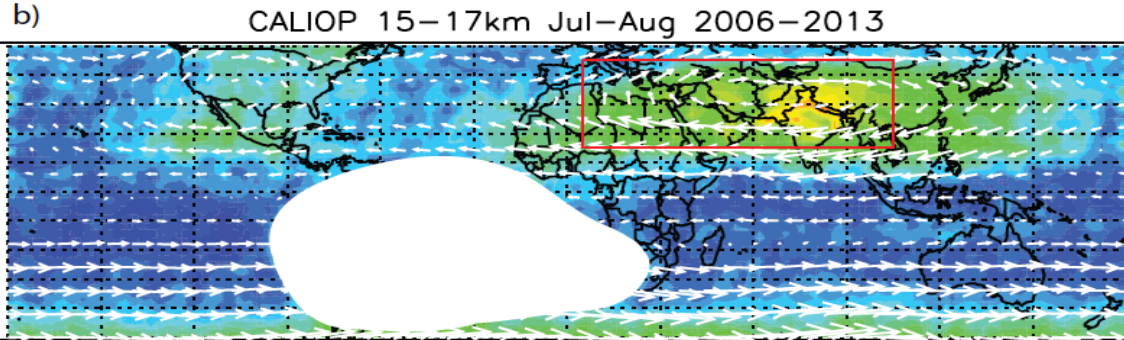
-CALIOP depolarization used to distinguish Ice Clouds and (low depolarizing) aerosol particles

-Note: All points shown within 15-17 km in Southeast Asia

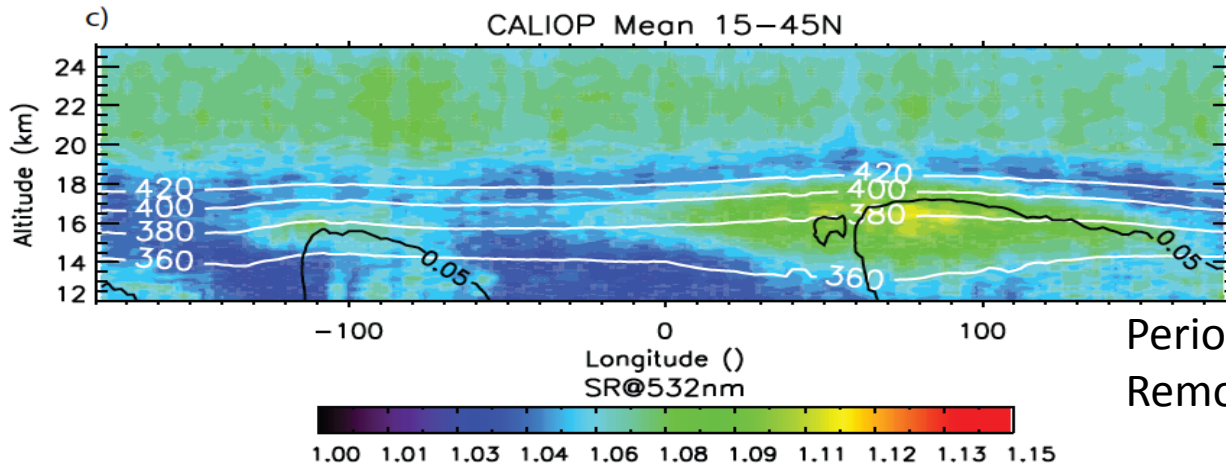
The Asian Tropopause Aerosol Layer



Time series of Cloud-filtered Scattering Ratio (SR) from CALIOP



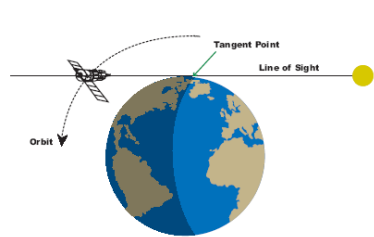
Jun-Aug mean map of SR (15 - 17km) and longitude cross-section (15-45°N), below.



ATAL shown by enhanced SR during Asian Monsoon; ATAL extends from top of convective outflow.

Periods affected by volcanic aerosol
Removed from map and section

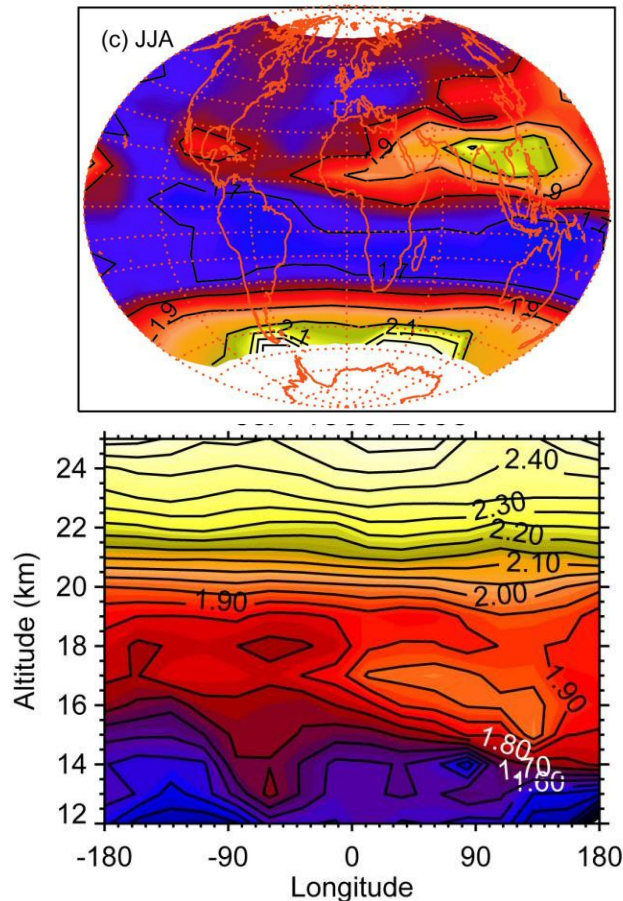
Vernier et al., (JGR, in review)



Evidence of ATAL from SAGE II and from balloon-sonde

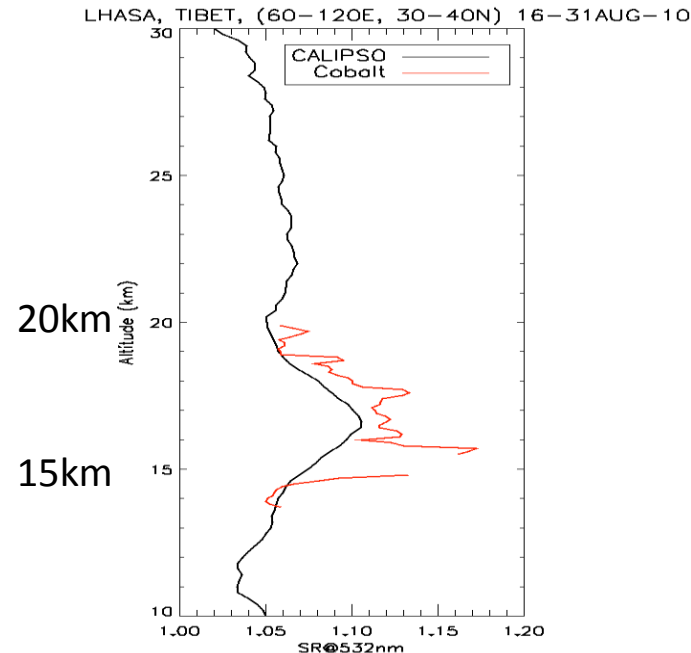


SAGE II JJA 1999-2005



SAGE II 1020 nm aerosol ext. ratio, 16° km, and 15-45°N; from Thomason and Vernier. (2013)

COBALD, Lhasa

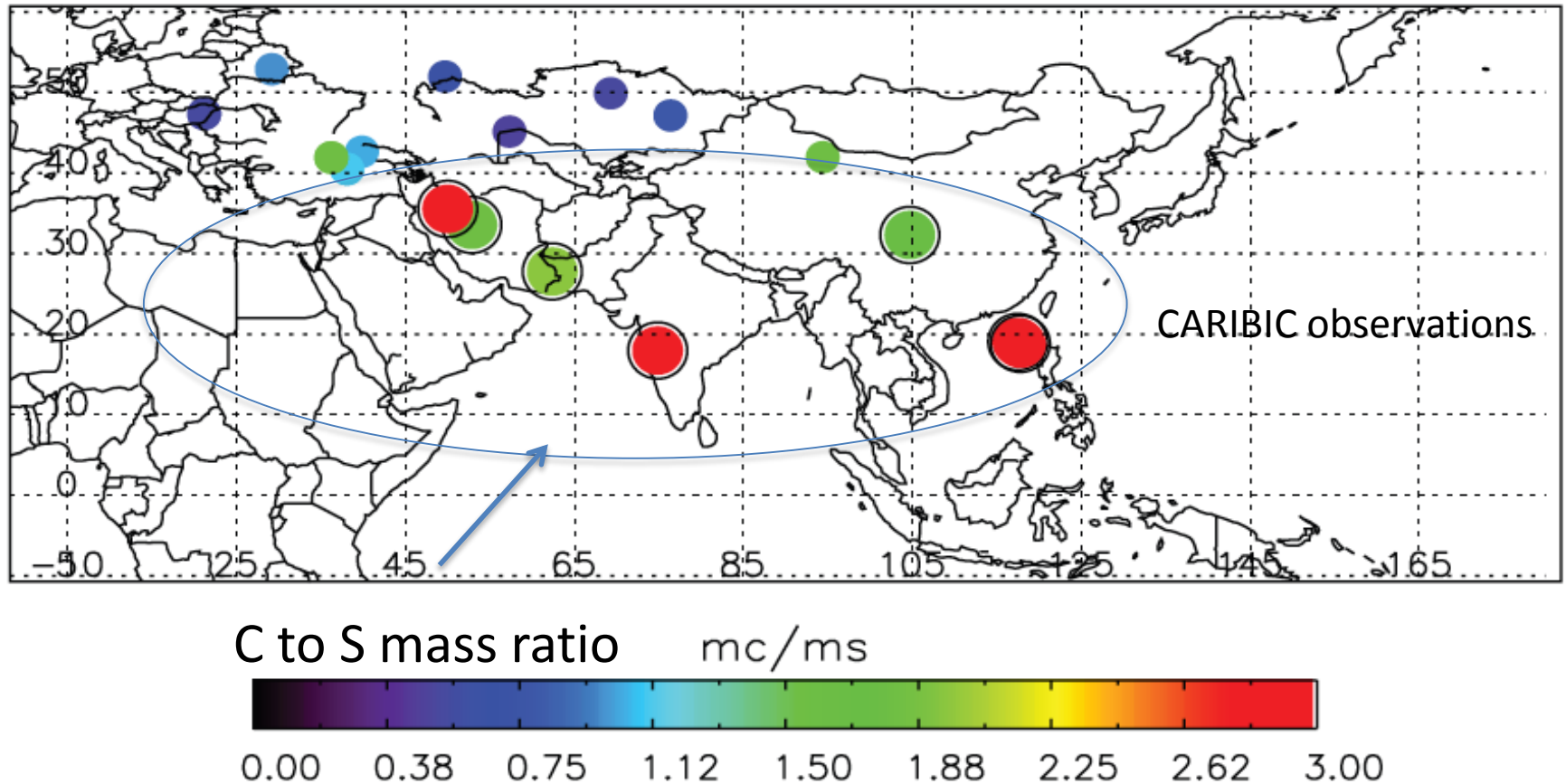


SR@532 nm

Maximum aerosol seen by SAGE II, 1999-2005
First confirmation by in situ (COBALD) SR in 2010 from Lhasa, Tibet (G. Wienhold (LUS), J. Bian, (CAS)) vs. mean CALIOP SR profile.

ATAL composition

CARIBIC AUG 2006–2008 elemental composition C/S (10–12 km)

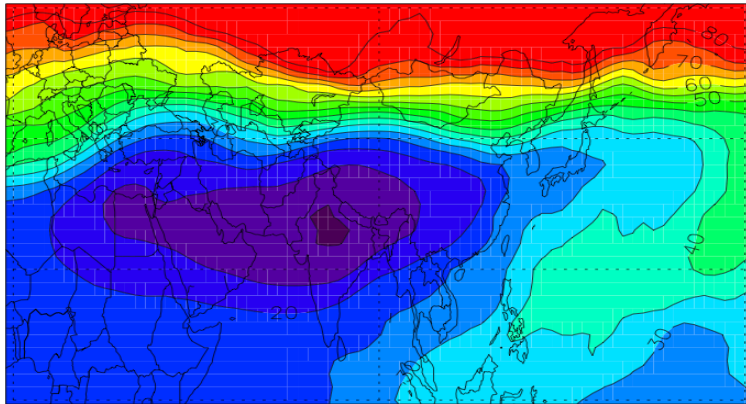


- Large fraction of carbonaceous aerosol observed in CARIBIC aircraft impactor data (B. Martinsson) in the Asian anticyclone

Vernier et al., 2014 (JGR, in review)

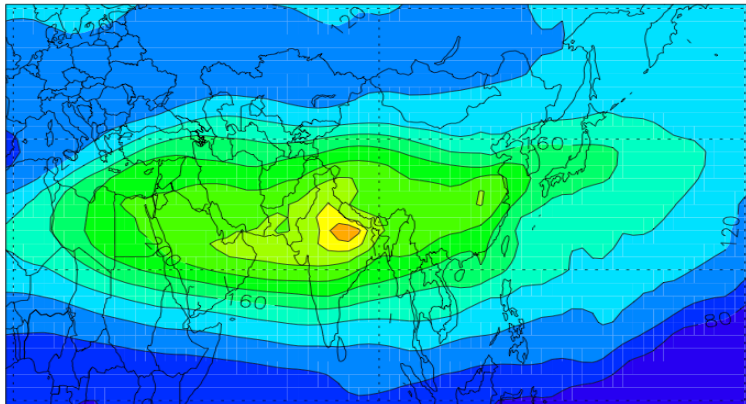
GEOS-Chem 360K maps for August 2008

SO₄ SO₄ 360K 20080801



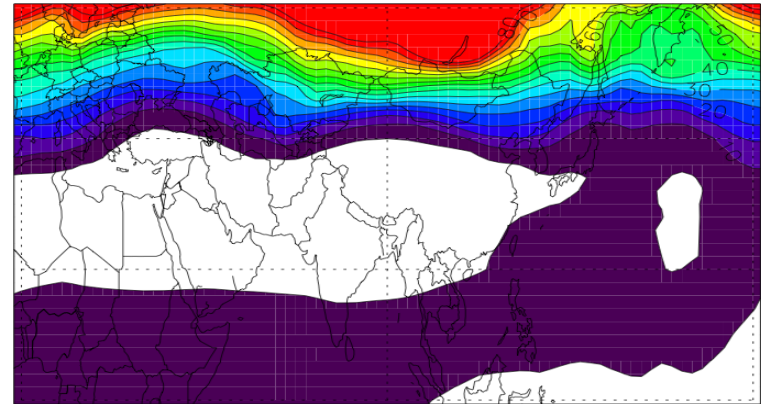
0.00 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0

ORGANIC Organic 360K 20080801 ppt



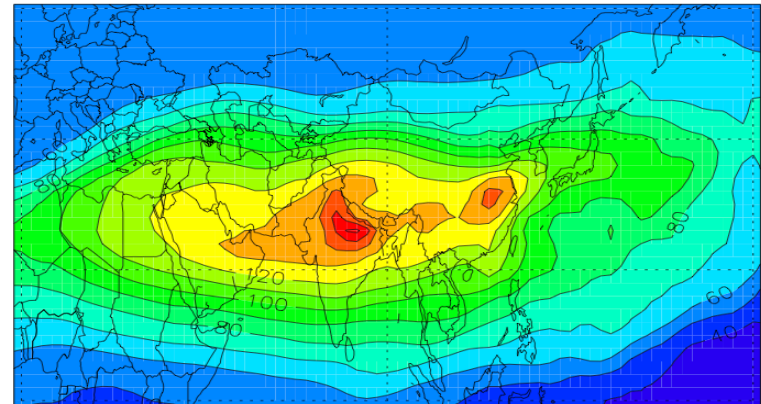
0.00 40.0 80.0 120. 160. 200. 240. 280. 320. ppt

SO₂ SO₂ 360K 20080801



0.00 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0

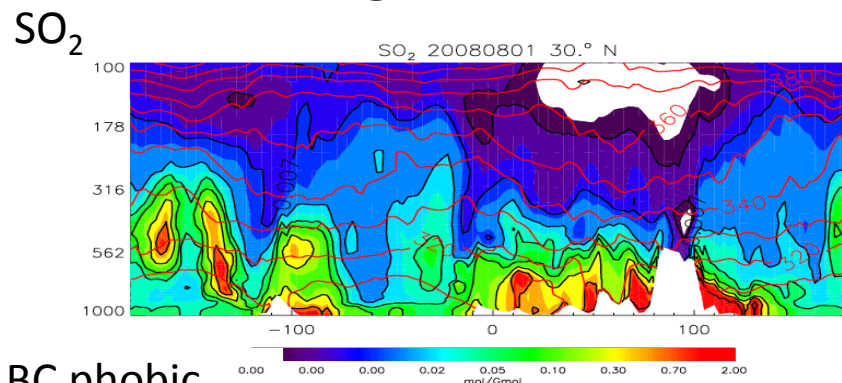
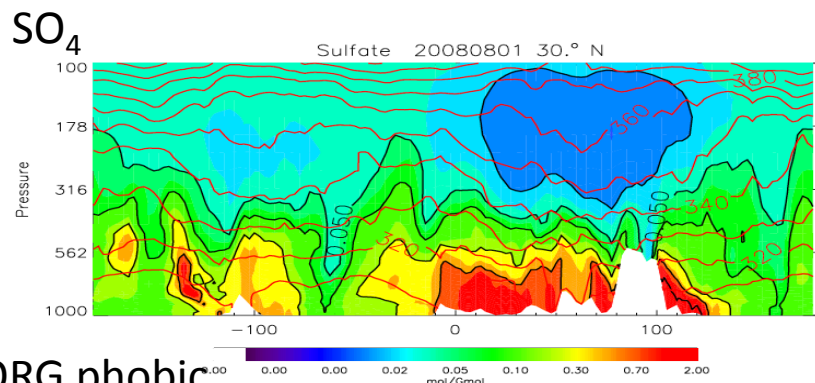
BC Black C 360K 20080801 ppt



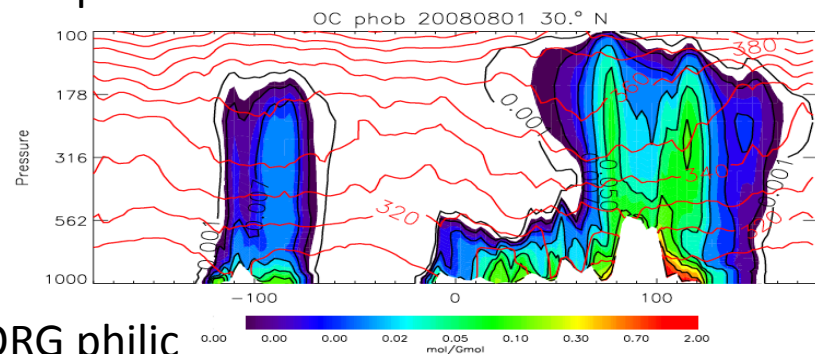
0.00 20.0 40.0 60.0 80.0 100. 120. 140. 160. ppt

Find minimum SO₄ (10-20 ppt), (and SO₂ (<10 ppt)) in ATAL; peaks in organic (120-240 ppt) and BC (80-140 ppt).

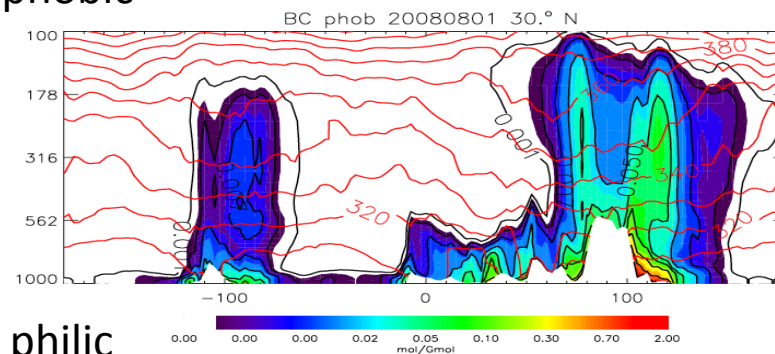
GEOS-Chem cross-sections at 30°N, August, 2008



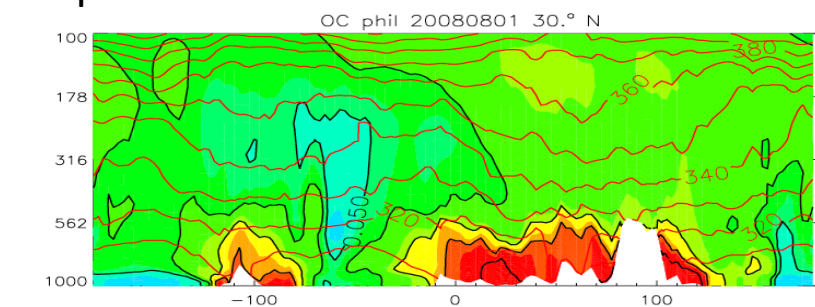
ORG phobic



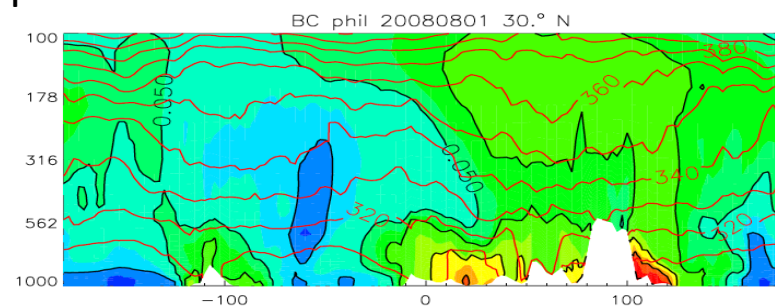
BC phobic



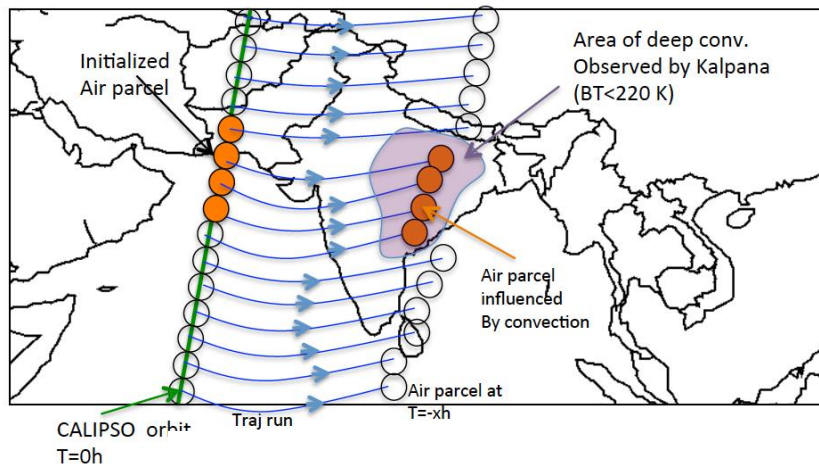
ORG philic



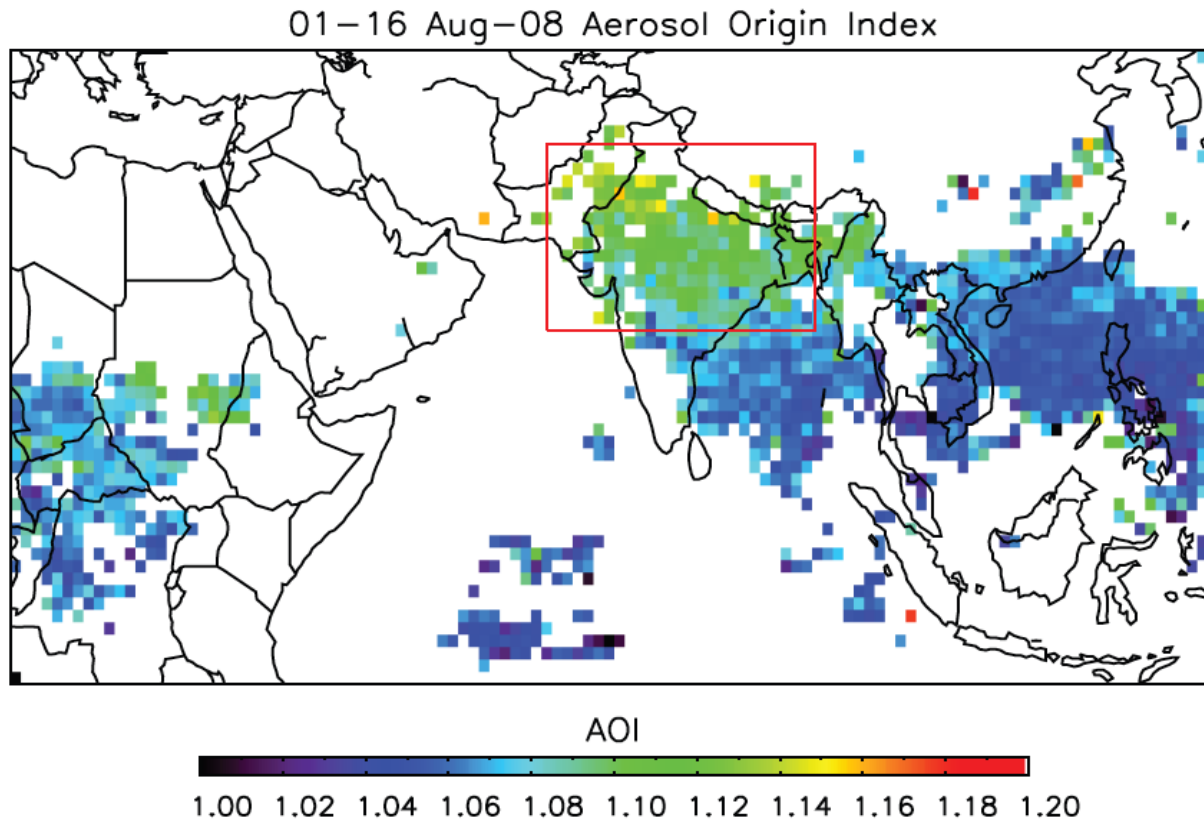
BC philic



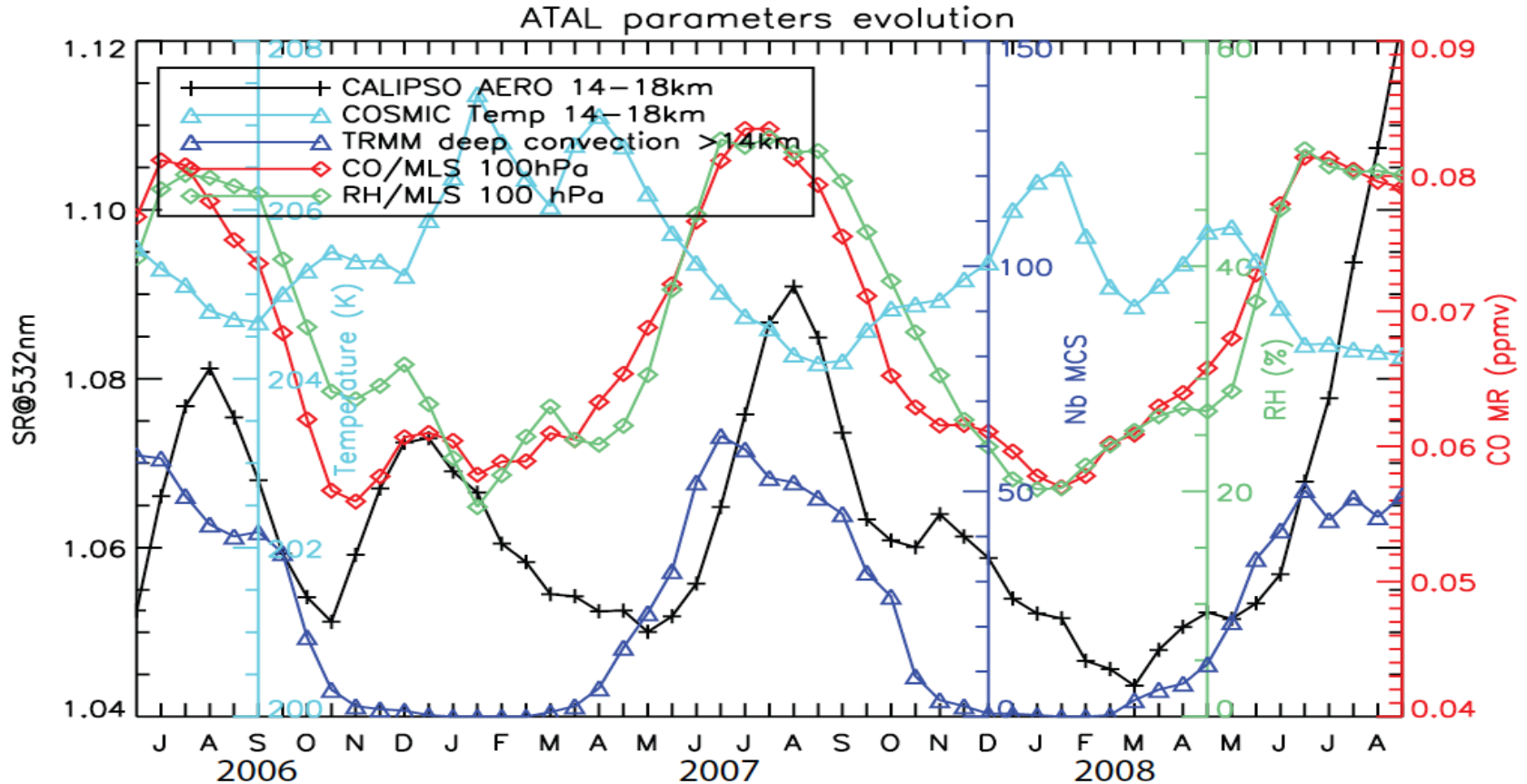
Convective transport shown by hydrophobic components; SO₄ (and SO₂) very efficiently Scavenged by precipitation



Left: Trajectory mapping from CALIPSO orbital data to regions of deep convection ($BT < 220 K$ from Kalpana); Bottom: Map of mean CALIPSO SR (AOI) for parcels sourced to deep convection, 1-16 Aug., 2008.



Times series of ATAL parameters



CO (red) increases with RHi (GRN), driven by convection (dark blue). Aerosol SR (black) lags CO by ~1 month in early summer; in phase with RHi mid-late summer. Consistent with RHi control of aerosol size, for existing particles lofted via deep convection.

Direct radiative effect of ATAL

- Summertime AOD associated with ATAL has increased from $\sim 0.002 - 0.006$ over 18 years. Low depolarization indicates spherical particles, e.g. sulfate, organics.
- Preliminary Top of Atmosphere (TOA) radiative forcing calculations: Sulfate/organics mix based on CARIBIC data: -0.12 Wm^{-2} (clear sky), -0.09 Wm^{-2} (total sky) cf: change in global TOA for $\text{CO}_2 \sim 0.3 \text{ Wm}^{-2}$ (2000-2010)
- Note: NASA Langley Fu – Liou radiative transfer code (Rose et al., 2006; Natarajan et al., 2012) inputs: T, P, O_3 , H_2O , COT, aerosol optical properties (Hess et al., 1998).

Conclusions

- SAGE II + CALIOP show amplification of ATAL since 1998.
- CALIOP observations validated by backscatter COBALD backscatter sondes. Low depolarization – spherical particles
- CARIBIC (aircraft) in-situ data and Geos-Chem model results suggest a large fraction of carbonaceous aerosol in ATAL. Other models (e.g. CAM5 show similar levels of sulfate and carbonaceous (Yu, and Toon).
- Northern India preferred region linked to high SR in UTLS.
- Potential Impact on climate ($\sim -0.12 \text{ W m}^{-2}$), composition dependent.